

Simulation of Lagrangian Drifters in the Labrador Sea

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LONG-TERM GOALS

The long-term goals of the Oceanic Planetary Boundary Layer (OPBL) Laboratory at the Naval Postgraduate School (NPS) are to understand the role of the OPBL in exchanging momentum, mass and energy between the ocean and the atmosphere, and to build and verify realistic models for OPBL processes in ocean circulation and air-sea interactions.

OBJECTIVES

The purpose of this study is to understand the motion and sensor response of drifting packages of scientific instruments in the Office of Naval Research's Accelerated Research Initiative (ARI) on Deep Oceanic Convection in the Labrador Sea (The Labrador Sea Group, 1998). Understanding the drifter response will lead to optimal strategies for deployment of drifting instruments, and it will help in the interpretation of observations obtained by instruments under the influence of oceanic convection. A key scientific objective is to understand the turbulent kinetic energy budget for free and forced deep oceanic convection, and the processes leading to deep penetrative convection in subpolar seas.

APPROACH

The method is to use nonhydrostatic oceanic large-eddy simulation (LES) to predict the unsteady three-dimensional turbulent velocity, temperature, salinity, and pressure fields on a model grid. Typical grid domains are 1-4 km deep by 3-12 km horizontally, resolving the OPBL turbulence from the integral scale (dominant turbulent eddy size) into the inertial range. These fields are archived or used directly to advect Lagrangian drifter models (LDM's). LDM's are designed to simulate a variety of drifter designs: pure Lagrangian, isobaric, glider, or propelled (AUV's). In addition to the PI, contributing OPBL Laboratory personnel include Mr. Ramsey Harcourt and LCDR Rebecca Stone. Ramsey Harcourt is a doctoral candidate at the University of California, Santa Cruz. The title of his dissertation is "Numerical Simulation of Deep Convection and the Response of Drifters in the Labrador Sea." Rebecca Stone is a Doctoral Candidate at NPS, focusing on understanding conditional instabilities in polar seas. The PI, Roland Garwood, is Chairperson of the Department of Oceanography at NPS.

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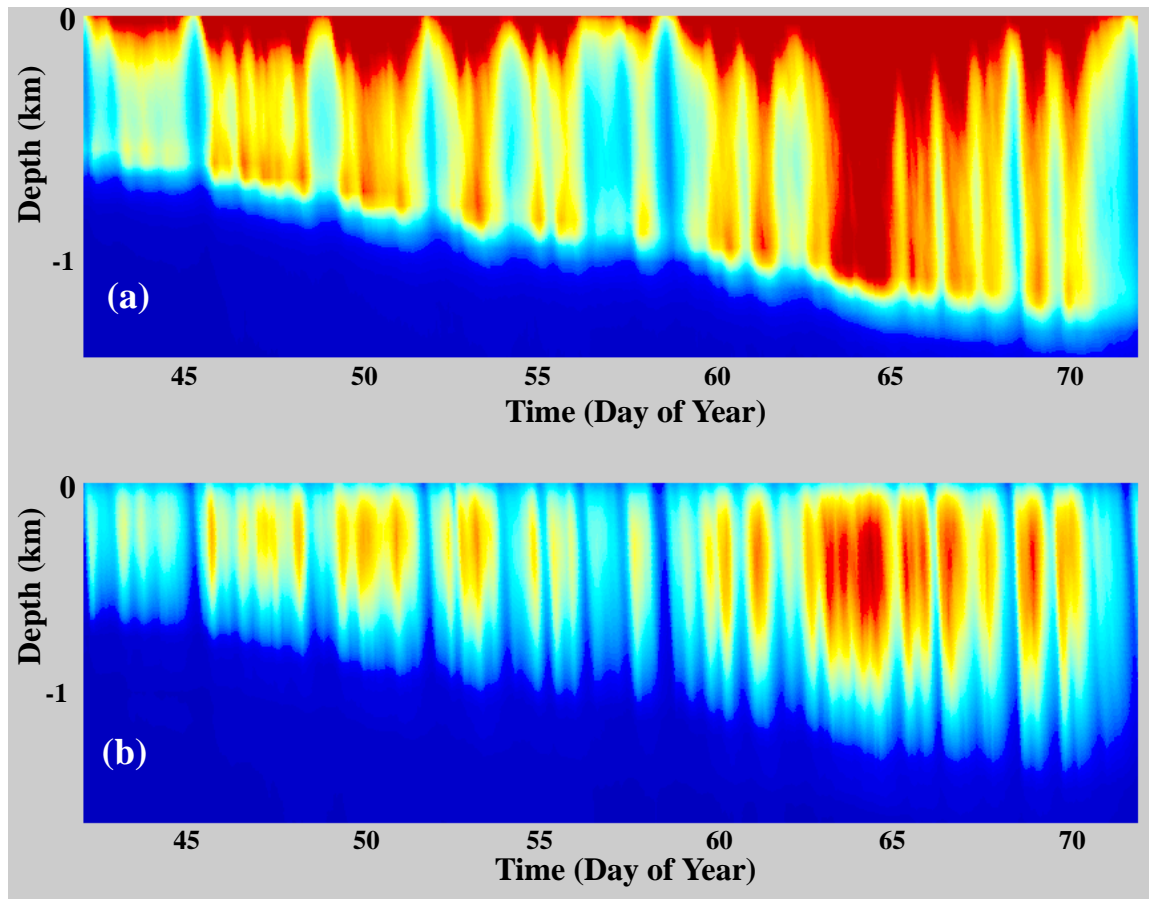


FIGURE 1. (a) Horizontal and (b) Vertical turbulent kinetic energy versus depth and time for 1997 Labrador Sea field experiment. Peak (red) values exceed 0.1 J/m^3 .

WORK COMPLETED

A major milestone passed during FY98 was the large-eddy simulation of Labrador Sea convection during the 28-day ship-observed focus period of the 1997 field experiment. Simulation of Lagrangian and isobaric drifters was conducted simultaneously. Model-generated data sets of the statistics for the flow fields, thermodynamic variables, and drifter trajectories have been archived for analysis.

RESULTS

Earlier results for idealized steady-state convection (Harcourt *et al.*, 1998), which neglected entrainment, have been shown to hold for the realistic unsteady simulation of the Labrador Sea during winter 1997. These results show clearly that isobaric (Rossby-type) drifters will sense mean fields for temperature and velocity that will be biased by the tendency for the fixed-depth drifters to seek out and maintain position in zones of horizontal convergence. Depending upon the ballasting depth, these drifters will experience a significant mean vertical velocity that is caused by the turbulence, not by a mean upwelling/downwelling. Although the Labrador Sea isobaric drifters deployed during the 1997 winter did not perform as designed, the LES-predicted biases have been confirmed by isobaric drifters released into the Greenland Sea (Gascard, personal communication; Lherminier, 1998).

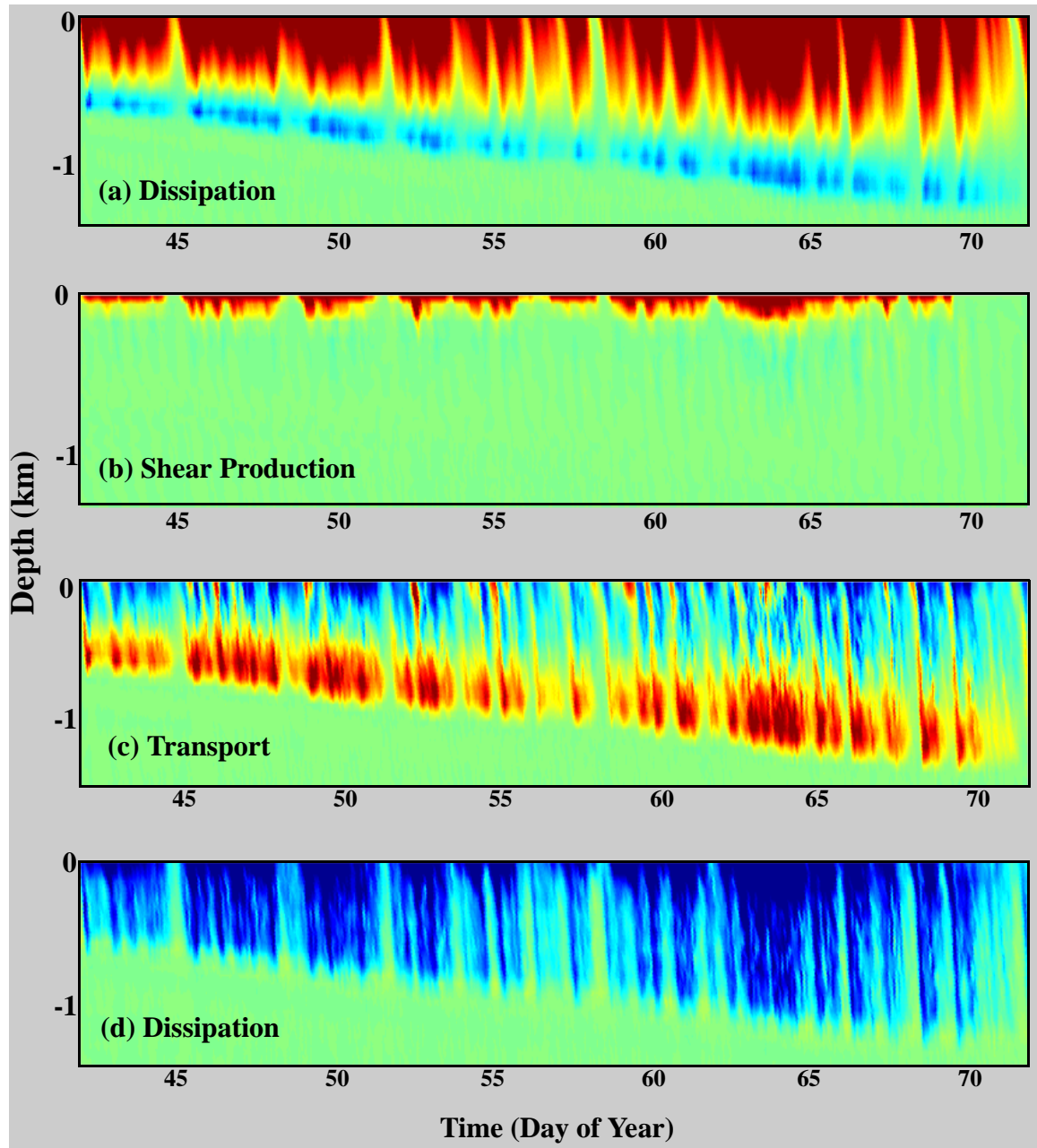


FIGURE 2. Hindcast TKE budget versus depth and day for the 1997 Labrador Sea experiment: (a) buoyancy flux, (b) shear production, (c) transport, and (d) dissipation. Maximum values (red) exceed 10^{-4}W/m^3 , and minimum (blue) value is -10^{-4}W/m^3 .

Shown in this report are the hindcast computations of the turbulent kinetic energy (TKE) components (Figure 1), the terms of the TKE budget (Figure 2), and the temperature and salinity variances (Figure 3). These computations of the turbulence statistics represent a time series of the horizontal averages (over 36 km^2) for the LES box domain, which is assumed to be carried by the barotropic flow in the vicinity of 57N and 54W .

These LES results have yielded several important new findings including:

- The horizontal TKE is surprisingly large, compared with the vertical TKE (Figure 1) for deep Labrador Sea convection. The reason is the large shear production of horizontal TKE near the surface that is subsequently transported vertically.
- The amount of penetrative convection is considerable. The entrainment zone is a negative buoyancy flux region that is frequently 100-200 m thick, below the well-mixed layer. An important new finding is the role of pressure transport in energizing the stable layers below the turbulence (Figure 2c). Pressure transport, unlike turbulent transport, may penetrate hundreds of meters into the pycnocline below the well-mixed turbulent layer.
- Variance in temperature is dominated by entrainment, not by the surface heat flux, even though the surface heat flux usually exceeds the entrainment heat flux. The large variances in both temperature and salinity (Figure 3) predicted by LES suggest that much of the patchiness observed in CTD profiles during the 1997 field experiment is explained by local forcing.

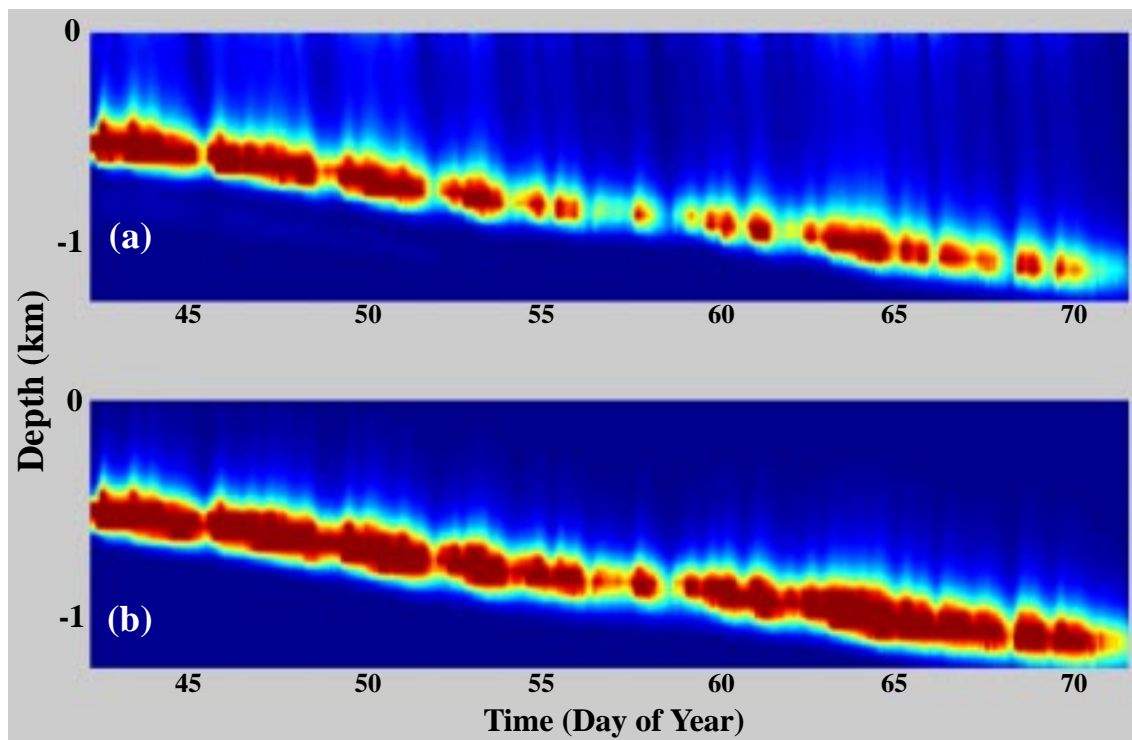


FIGURE 3. Hindcast calculations of variances of (a) temperature (C^2) and (b) salinity (psu^2) versus depth and day for 1997 Labrador Sea field experiment. Peak variances (red) exceed $2 \times 10^{-3} C^2$ and $5 \times 10^{-5} psu^2$, respectively.

IMPACT/APPLICATIONS

Planetary rotation has significant effects upon the TKE and upon entrainment. None of the simulations of Labrador Sea deep convection were found to be realistic without both horizontal and vertical Coriolis components. This shows clearly the need to include rotation in mixed-layer models for convection (Garwood, 1991; Garwood *et al.*, 1985). Improved mixed layer parameterization for both dissipation and pressure redistribution will lead to improved mixed layer performance for basin-scale ocean models. Figure 4

shows an improved mixed layer model's prediction of total and vertical turbulent velocities versus Rossby number, together with verification by LES.

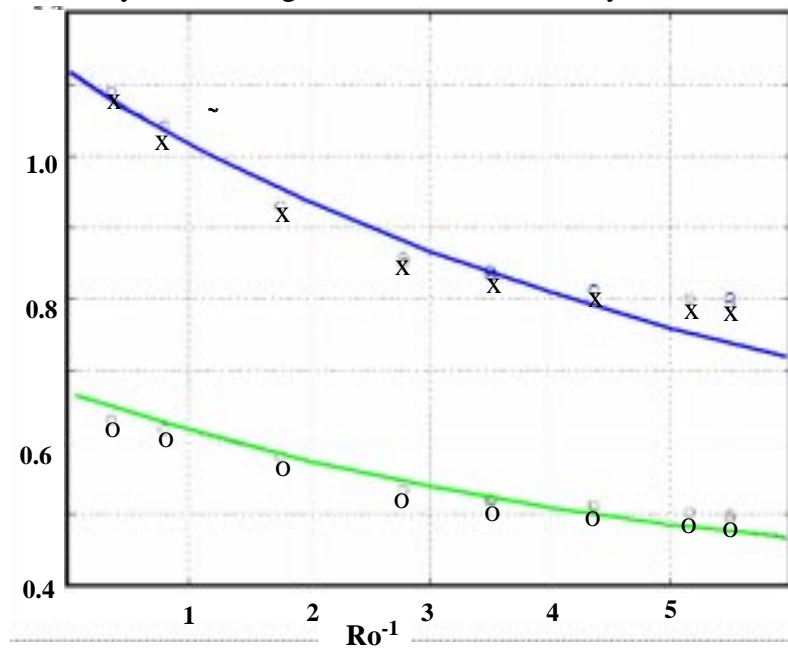


FIGURE 4. Rossby number ($Ro=w^*/hf$) dependence for the total rms turbulent velocity (blue line) and vertical rms turbulent velocity (green line). Turbulent velocities are nondimensionalized on the convection velocity scale w^* . LES calculations are the x's and o's. The new mixed-layer model gives the solid lines.

TRANSITIONS

Firstly, results concerning the advection of freely-drifting bodies have direct implications for all drifting material in the ocean (Garwood *et al.*, 1998), including suspended matter and plankton that affect the optical properties of seawater. Secondly, LES has important future application in the shelf and nearshore regions because of the need to include nonhydrostatic acceleration over ocean topographic features having horizontal scales less than a few kilometers. Thirdly, LES can help explain the ocean surface's radar signature (Fischer *et al.*, 1998), as well as the other surface properties detected by remote sensing.

RELATED PROJECTS

1 - The OPBL Laboratory is supported by the National Science Foundation to study Polar Sea Conditional Instabilities. This project examines processes that may lead to bottom water formation, including thermobaric parcel and layer instabilities (Garwood *et al.*, 1994), and the interaction between mesoscale motion and plume-scale turbulence in forming three-dimensional bottom plumes (Jiang and Garwood, 1996).

2 - Another OPBL Laboratory project is "Tropical Mixed Layer System," sponsored by NOAA and NSF. In this project, turbulence closure is used to parameterize mixed layer dynamics in basin-scale OGCM's. Study focuses on processes including the interaction between equatorial shear zones and turbulent mixing layers, as a function of surface forcing anomalies such as westerly wind bursts and precipitation associated with El Nino.

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